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by

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ABSTRACT

This Paper provides a Literature Review of selected, published literature relative to the performance of certain pollution control technologies that have been applied to Waste-to-Energy (WTE) plants. It discusses various environmental standards which have been adopted by three European countries and three U.S. States for WTE plants. The Paper describes the pollutant emissions and residues exiting plants of this type, and delineates the performance of two Canadian air pollution control technology pilot plants applied to the flue gases of such plants.

ENVIRONMENTAL CONTROLS FOR WASTE-TO-ENERGY PLANTS

INTRODUCTION

Large volumes of organic solid wastes are generated in man's everyday activities. These wastes are generated in the home, in commercial establishments and throughout the Nation's varied industrial operations. Over the years, relatively little attention has been paid to the final disposition or utilization of these wastes. Due to this lack of attention, many environmental insults resulted from the disposal of these wastes - - - insults such as open-burning, leaching dumps, and improper discharges to surface and groundwaters. These insults led to the initial passage in the United States (U.S.) of the 1965 Solid Waste Disposal Act, followed by the 1970 and 1976 Resource Recovery Acts and their subsequent Amendments. These Acts mandated the Federal Government (EPA and its predecessor Agencies) to support research and demonstrations to develop and apply new or improved technologies for recovering materials and energy from solid wastes. This mandate, coupled with the U.S. Department of Energy's (DOE's) more recent concern over our dwindling energy supply, has focussed our Nation's attention on the utilization of these wastes as sources of energy. Many options to utilize these wastes as energy resources have been investigated. Options have varied from combustion in waterwall or mass-burning incinerators, to co-firing of prepared wastes with coal in industrial boilers, to the thermochemical or pyrolytic conversion of these wastes into usable fuel products.[1,2]

This Paper will discuss various environmental standards which have been adopted by selected countries and States for Waste-to-Energy plants, the environmental characteristics of some of these plants, and the performance of certain pollution control technologies applied to such plants. Because EPA elected to remove itself from research in the Waste-to-Energy area in 1980[2], this Paper will concentrate on recent control-technology research results obtained by the Canadian Government (by their Environment Canada), not by the U.S. Environmental Protection Agency.

ENVIRONMENTAL STANDARDS FROM AROUND THE WORLD

Regulations applicable to municipal incinerators (or "Waste-to-Energy Plants," as they are referred to here) have been adopted throughout Europe and by various States within the U.S. The only Federal standard that governs plants of this type in the U.S. is the New Source

Performance Standard for particulates, i.e., the limit of 0.08 grains of dust/standard cubic foot of exhaust gas. While new Federal standards are being considered in this country, some individual States have either passed or are in the process of passing new regulations for these plants.[3] Table 1 lists several standards that are in effect in Europe and in various States of the U.S.[3,4,5,6,7]

As can be seen from Table 1, the particulate limit for West Germany (30 mg/Nm^3, milligrams per normal cubic meter) falls between the limits for California and Connecticut, 0.010 and 0.015 gr/dscf (grains per dry standard cubic foot) respectively. Also, the new Swedish limit of 20 milligrams of particulate per normal cubic meter is the most stringent of the six listed in Table 1. The Swedes have also set limits for mercury, cadmium and thallium emissions (of 0.20 mg/Nm^3 each).[3] The Germans and the Danes have set limits on carbon monoxide (CO) emissions, each at 100 mg/Nm^3 as daily averages; in Germany, 200 mg/Nm^3 is the maximum CO level allowed, while in Denmark, excursions up to an average of 800 mg/Nm^3 are allowed over any 1-minute interval.[5] When the recent 16-month moratorium on building new Wasteto-Energy plants was lifted in Sweden in June, 1986, the Swedish Government established Guidelines for dioxin and furan emissions from these plants as also shown in Table 1; these Guidelines are intended as limitations to strive for during a plant's operating trial period, with definitive limits to be established after that trial period.[6]

POLLUTANT EMISSIONS/RESIDUES FROM WASTE-TO-ENERGY PLANTS

Many field-testing and research activities have been carried out in an attempt to characterize the emissions and residues from Waste-to-Energy (WTE) plants. The results from some of these efforts will be summarized below; in particular, these pollutant emissions and residue streams will be discussed:

In Flue Gases	In Ash Streams
• Dioxins/Furans	• Dioxins/Furans
• Other Organics	• Other Organics
• Metals	• Metals
• HCl	
• SO_2	
• CO	

The characteristics of typical flue gas streams will be described first, followed by a description of what pollutant levels have been found in selected ash streams from WTE plants.

TABLE 1. CURRENT EMISSION CONTROL REGULATIONS FOR WASTE-TO-ENERGY PLANTS*

	U.S. State[3,4]			Country		
Constituent	California	Connecticut	New Jersey	West Germany[3,4]	Denmark[5]	Sweden[6]
• Solid Particulate	0.01 gr/dscf or 0.008 gr/dscf for solids less than 2 microns	0.015 gr/dscf	0.02 gr/dscf	30 mg/m^3 [0.013 gr/dscf]		20 mg/m^3
• Mercury				0.20 mg/m^3(3)		0.08 mg/m^3
• Carbon Monoxide				100 mg/m^3	100 mg/m^3	
• Hydrogen Fluoride				2 mg/m^3		
• Hydrogen Chloride	30 ppm	50 ppm	50 ppm or 90% weight reduction	50 mg/m^3		100 mg/m^3
• Sulfur Dioxide	30 ppm	0.32 lb/MMBtu	100 ppm or 70% weight reduction	100 mg/m^3 [38 ppm]		
• Organics (THC)				20 mg/m^3		
• Dioxins/Furans (Guideline only)						0.5-2.0 ng/m^3 (Existing Plants)** 0.1 ng/m^3 (New Plants)**
Correction Gas (percentage)	12% CO_2 dry basis	12% CO_2 dry basis	7% O_2 dry basis	11% O_2 dry basis	10% O_2 dry basis	10% CO_2 dry basis

* For purposes of this Table, m^3 = Nm^3; mg = 10^{-3}g = 1/1000 gram; ng = 10^{-9}g; MMBtu = 10^6 Btu; THC = Total hydrocarbon.

** Limits are expressed as "TCDD-equivalents, as calculated by the Eadon (New York State) model."[6,7]

Dioxins/Furans (PCDD/PCDF) in Flue Gases

"Dioxins" is the common name given to the collection of 75 chemically-related compounds known as the congeners or isomers of polychlorinated dibenzo-p-dioxins (PCDDs). These congeners are identified by the number and position of their chlorine atoms (up to 8 chlorines per molecule). For example, the most famous (and the most toxic) of these congeners is 2,3,7,8-tetrachlorodibenzo-p-dioxin or 2,3,7,8-TCDD; its chemical formula is $C_{12}H_4Cl_4O_2$ and it has a molecular weight of 322. The summation of the 22 "tetra" congeners are known collectively as "TCDD" or "T4" for short. Likewise, the 14 "penta" isomers (each $C_{12}H_3Cl_5O_2$) are known as "P_5CDD" or P5 ... and so forth. Similarly, "furans" (PCDFs) refers to the polychlorinated dibenzofurans; there are 135 congeners that combine to form the PCDFs. TCDFs refers to the collection of the 38 "tetra" congeners; "H_6" refers to the 16 "hexa" congeners, "H7" refers to the 4 "hepta" isomers, and "O8" refers to the single "octa" isomer.[8]

Table 2 gives a summary of the average PCDD and PCDF congener concentrations and the calculated total (T4 to O8) values for WTE plant emissions.[8] It shows that the average total (T4 to O8) PCDD and PCDF concentrations in fly ash precipitated from flue gas are 1,318 and 1,072 nanograms per gram (ng/g) respectively or, taken collectively, are 2.390 micrograms per gram (μg/g) or 2.39 parts per million (ppm). Table 2 also shows that PCDD/PCDF concentrations in "stack-collected particulates" (particulates which escape the pollution control devices) average 3.474 and 7.414 μg/g (ppm) respectively. Table 2 also attempts to subdivide the "Total Stack Emissions" of PCDD and PCDF into solid-phase particulates and gaseous-phase emissions (though the two phases are not additive due to the different bases used in their derivation).[8] It shows that Total Stack Emissions of PCDD average 4,263 ng/m^3 and of PCDF average 3,850 ng/m^3 over the 20 or so mostly European and Canadian plants tested that reported both particulates and gaseous phases for their emissions.[8] These averages approximate 3.3 and 3.0 parts per billion, ppb, for PCDD and PCDF respectively --- i.e., taken together, about 6.3×10^{-9} grams of dioxins and furans per gram of flue gas are typically emitted from Waste-to-Energy (WTE) plants.

Table 3 gives some site-specific PCDD and PCDF emission data from some 16 U.S., Canadian and European WTE plants.[9] It shows a phenomenal range in total PCDD plus PCDF stack emissions of 0.03 to 37,000 ng/Nm^3 (or from about 23×10^{-15} g/g to about 29×10^{-9} g/g, i.e., 23 parts per quadrillion to 29 ppb). This is truly a wide range of values that cover the span from "most efficient" (in terms of combustion and air pollution control efficiency) to "least efficient."

Other Organics in Flue Gases

Other trace organics, in addition to dioxins and furans, are emitted from Waste-to-Energy plants. The organics include chlorobenzenes

TABLE 2. SUMMARY OF AVERAGE PCDD AND PCDF CONGENER CONCENTRATIONS AND CALCULATED TOTAL (T4- 08) VALUES FOR MUNICIPAL WASTE INCINERATOR EMISSIONS[8]

Matrix	Units**	PCDD						PCDF						Total* (T_4-O_8) PCDD + PCDF
		T4	P5	H6	H7	08	Total* (T_4-O_8)	T4	P5	H6	H7	08	Total* (T_4-O_8)	
- Weight Basis -														
Precipitated Fly Ash	ng/g Ave.	90	151	528	322	227	1318	151	245	379	250	47	1072	2390
	n	44	24	35	26	45		28	14	23	14	32		
	s.d.	321	394	1265	680	344		172	271	527	348	61		
Stack-Collected Particulates	ng/g Ave.	502	723	1003	700	546	3474	2321	2345	2076	558	114	7414	10888
	n	5	5	5	5	5		4	4	4	5	5		
	s.d.	901	925	1170	778	787		4123	3787	1786	653	154		
- Volume Basis* -**														
Stack-Collected Particulates	ng/m^3 Ave.	49	71	1186	104	654	2064	150	283	218	88	240	979	3043
	n	13	11	11	11	13		11	5	5	5	13		
	s.d.	112	126	3595	189	2005		370	476	279	121	795		
Stack-Collected Gaseous Phase	ng/m^3 Ave.	45	59	3588	151	492	4335	465	313	159	33	671	1641	5976
	n	12	10	10	10	12		10	4	4	4	12		
	s.d.	104	107	8334	247	798		615	560	257	50	1295		
Total Stack Emissions****	ng/m^3 Ave.	338	290	2551	343	741	4263	1353	1205	378	296	618	3850	8113
	n	19	16	20	20	22		17	10	11	11	19		
	s.d.	1062	635	8614	516	1835		3177	2151	558	638	1673		

* Total = Calculated from sum of average isomer group values.
** n. = number of values averaged.
s.d. = standard deviation
*** Data for Nm^3 (m^3) and dscm averaged without correction ($1 Nm^3$ = 0.925 dscm).
****Total of gaseous plus particulate phases for only those studies where both phases were reported.

TABLE 3. PCDD AND PCDF EMITTED BY VARIOUS WTE PLANTS[9]

Plant Location		Stack Emissions, ng/Nm^3		
		PCDD	PCDF	Total
Hampton, VA	max	13,000	24,000	37,000
	min	670	3,000	3,670
Hamilton, ONT	max	1,700	7,000	8,700
	min	1,300	4,000	5,300
Chicago, IL	max	61	490	551
Albany, NY	avg	300	88	388
Victoria, BC	max	84	197	281
	min	57	117	174
Zurich, SW	avg	113	89	202
Prince Edward Island, ONT	max	123	156	279
	min	64	100	164
Stapelfeld, WG	max	40	120	160
	min	20	90	110
Peekskill, NY	avg	18	40	58
Pittsfield, MA	max[Note 1]	76	270	346
	min	24	38	62
Wurzburg, WG	max	36	54	90
	min	12	10	22
Quebec City, ONT	in[Note 2]	1,030	560	1,590
	out	0.4	0.9	1.3
Neustadt, WG	in[Note3]	80	95	175
	out	5	9	14
Tulsa, OK	avg	19	16	35
Marion County, OR	max	1.5	0.6	2.1
	min	0.8	0.3	1.1
Montreal, Q[Note4]	March	0.75	0.54	1.29
	November	0.01	0.02	0.03

Notes:
1. Lowest and highest practical furnace temperatures during diagnostic test program [10]
2. In and out of dry lime scrubber[11]
3. In and out of wet scrubber [12]
4. VonRoll furnace, lime fed with MSW[13]

(CBs), chlorophenols (CPs), polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs). Since emission data on these pollutants and those yet to be discussed in this Paper are somewhat limited, extensive use will be made hereafter of the emission and control data gathered in a 1985 pilot-scale research study done jointly at the Quebec City Municipal Solid Waste Incinerator Plant by Environment Canada (under their National Incinerator Testing and Evaluation Program, NITEP) and Flakt Canada Ltd.[11,14] Using the NITEP data, it can be demonstrated that the emissions of CBs, CPs, PCBs and PAHs varied as shown below over the 6 tests conducted there:[14]

Pollutant	Emission Range*, ng/Nm^3
• CBs	100 - 2700
• CPs	230 - 8300
• PCBs	0.14 - 9.2
• PAHs	15 - 250

*Emissions exiting the 2-stage pilot-scale dry scrubber/ fabric filter tested at Quebec City (at 8 percent O_2).

Metals in Flue Gases

Metal analyses of the pilot plant's particulate emissions (i.e., downstream of the 2-stage air pollution control system) were also carried out during the Quebec City tests; 27 metals were detected in all --- the range in values for the 8 most significant ones (over the 6 pilot-scale tests done) appear below:[14]

Metal	Emission Range, $\mu g/Nm^3$ at 8% O_2
• Zinc (Zn)	5 - 10
• Cadmium (Cd)	Not detected - 0.6
• Lead (Pb)	1 - 6
• Chromium (Cr)	0.2 - 1
• Nickel (Ni)	0.4 - 2
• Arsenic (As)	0.02 - 0.07
• Antimony (Sb)	0.2 - 0.6
• Mercury (Hg)	10 - 610

The overall level of particulates in the pilot's fabric filter outlet was typically below 2 mg/Nm^3.

HCl, SO_2 and CO in Flue Gas Emissions

Hydrogen chloride (HCl), sulfur dioxide (SO_2) and carbon monoxide (CO) emissions were also determined during the Quebec City pilot plant tests. The two-stage air pollution control system tested there produced

this range of outlet values for these pollutants:[14]

Pollutant	Emission Range, ppm at 8% O_2
• HCl	7 - 91
• SO_2	4 - 83
• CO	130 - 220*

*At 12-13% O_2.

The range of CO values for the data contained in Table 3 (for selected, mostly full-scale Waste-to-Energy, WTE, plants) was 14 to 1000 ppm, with the lowest values (14-17 ppm) being recorded at the Marion County, Oregon plant.

Dioxins/Furans (PCDD/PCDF) in Ash Streams

Within the air pollution control pilot plant studied at Quebec City, there were 3 sources of ash. The percentage of how much ash was collected in each vessel (or source) is shown in Table 4, depending upon whether the "Dry System" or the "Wet-Dry System" was used for pollution control.[14] (These two Systems will be described in detail below, in the "Pollution Control Technologies Performance" section of this Paper.) As Table 4 shows, when the incinerator flue gases flowed through the air pollution control system, some fly ash was removed in the scrubbers and the rest of the fly ash, plus reacted lime, was taken out in the fabric filter. The concentration ranges of PCDD and PCDF in the hopper ashes from these 3 vessels (in ng/g or ppb) is shown in Table 5.[14] Depending on the source of the ash, the PCDD concentrations in the ash are seen to vary from 6 to 740 ppb, while the PCDF values range from 4 to 380 ppb. The ash from the fabric filter exhibited the highest PCDD/PCDF concentrations.

Other Organics in Ash Streams

Table 6 gives the approximate range of concentrations of chlorobenzenes (CBs), chlorophenols (CPs), polychlorinated biphenyls (PCBs) and polychlorinated aromatic hydrocarbons (PAHs) that Environment Canada measured in their 3 ash streams during the Quebec City tests.[14] It shows that the CBs in ash can vary from 100 ppb to 3.3 ppm; CPs from 100 ppb to 8.5 ppm, PCBs from 0.2 to 24 ppb, and PAHs from about 20 ppb to 2.3 ppm.

Metals in Ash Streams

Table 7 gives the approximate concentration-in-ash range for the same 8 significant heavy metals as was given earlier in discussing their levels in typical, well-controlled (i.e., Quebec City) WTE flue

TABLE 4. PROPORTION OF ASH COLLECTED IN EACH VESSEL[14]

Source of Ash	Dry System	Wet-Dry System
• Wet-Dry Scrubber (or Flue Gas Conditioning Tower)	30%	33%
• Dry Scrubber	40%	_*
• Fabric Filter	30%	67%
	100%	100%

*Not Applicable = N/A

TABLE 5. PCDD AND PCDF CONCENTRATION RANGES IN VARIOUS ASHES (in ng/g or ppb)[14]

	Dry System		Wet-Dry System	
	PCDD	PCDF	PCDD	PCDF
• Wet-Dry Scrubber Ash	6-14	4-12	6-12	5-8
• Dry Scrubber Ash	31-160	22-87	N/A	N/A
• Fabric Filter Ash	280-740	160-380	160-230	130-170

TABLE 6. APPROXIMATE CONCENTRATION RANGES FOR CBs, CPs, PCBs AND PAHs IN VARIOUS ASH STREAMS (in ng/g or ppb)[14]

	CBs	CPs	PCBs	PAHs
• Wet-Dry Scrubber Ash	100-300	100-300	0.2 - 0.5	20-350
• Dry Scrubber Ash	300-800	400-1200	1.0 - 1.8	40-80
• Fabric Filter Ash	1700-3300	2700-8500	2.5 - 24	200-2300

TABLE 7. APPROXIMATE CONCENTRATION RANGES FOR Zn, Cd, Pb, Cr, Ni, As, Sb and Hg IN VARIOUS ASH STREAMS (in μg/g or ppm)[14]

	In Wet-Dry Scrubber Ash	In Dry Scrubber Ash	In Fabric Filter Ash
• Zinc (Zn)	3800 - 5200	7500 - 8000	11,500 - 22,000
• Cadmium (Cd)	30 - 40	65 - 70	160 - 340
• Lead (Pb)	1200 - 1600	2000 - 2300	5000 - 9300
• Chromium (Cr)	170 - 250	270 - 340	160 - 220
• Nickel (Ni)	70 - 160	90 - 170	40 - 95
• Arsenic (As)	4 - 7	5 - 10	14 - 50
• Antimony (Sb)	30 - 50	40 - 50	150 - 380
• Mercury (Hg)	2 - 8	22 - 38	75 - 300

gas emissions. It shows that arsenic was the lowest in concentration, with an overall range (across all the ashes) of about 4 to 50 ppm. Zinc was highest in concentration, with an overall range of 0.38 to 2.2 percent. Lead was the next highest in concentration, with a range in ash from 0.12 to 0.93 percent.[14]

POLLUTION CONTROL TECHNOLOGIES PERFORMANCE

As relied upon heavily above, the Quebec City tests will also serve as the key experience and source of data for this section of the Paper. This major research activity by Environment Canada will be summarized below. They used basically 2 pilot plant arrangements, each about 4000 acfm (actual cubic feet per minute), each designed and provided by Flakt Canada Ltd. Figures 1 and 2 provide schematics of the 2 pilot plants utilized, one called a "Dry System" and the other a "Wet-Dry System."[14] The Dry System (Figure 1) involves partial cooling of the hot flue gas with quench water, followed by contact with dry lime in the "dry scrubber" located immediately downstream. The effluent from there goes to a conventional fabric filter for removal of essentially all particulate material and reaction products from the dry scrubber. Four different levels of flue gas cooling were tested at Quebec City (cooling to 110°C, 125°C, 140°C and >200°C). The Wet-Dry System (Figure 2) basically combines the cooling step with the reaction-with-lime step into one reactor. Here, the hot flue gas is contacted with a slurry of water that has some hydrated lime dissolved in it. The temperature and slurry rate are carefully controlled to ensure that all the slurry water is totally evaporated and the dissolved lime goes into suspension as a fine particulate in the gas, which of course gets removed by the downstream fabric filter. Two operating sequences were tested for the Wet-Dry System --- both were at 140°C, one with and one without ash (lime) recycle from the fabric filter to the lime feed/mixing vessel.[14]

Control of Dioxins/Furans

The performance of the two 4000-acfm (~ 7000 acmh, actual cubic meters per hour, each) pilot plant systems ("Dry" and "Wet-Dry") for dioxin/furan control is shown in Tables 8 and 9.[14] PCDD and PCDF concentrations are shown at the inlet to the first stage of the control system, downstream of the first stage (the "Mid Point"), and at the outlet of the second stage, the fabric filter. Pollution control removal efficiencies are shown for the first stage ("Inlet/Midpoint") and for both stages taken together (i.e., the "Overall" efficiency noted). The results show that, while the Dry Scrubber alone with its dry lime injection feature was ineffective in removing PCDDs and PCDFs (with efficiencies ranging from minus 11% to plus 60%), the overall system was very efficient with efficiencies ranging from 99.3% to over 99.9% due to the superior performance of the

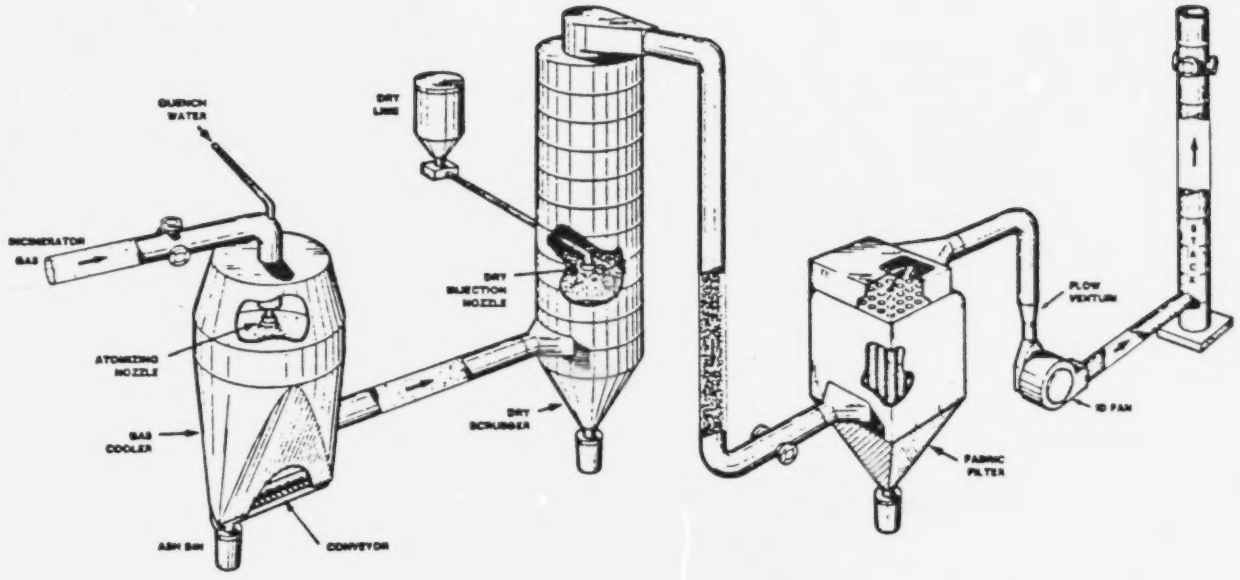

Figure 1. Dry System

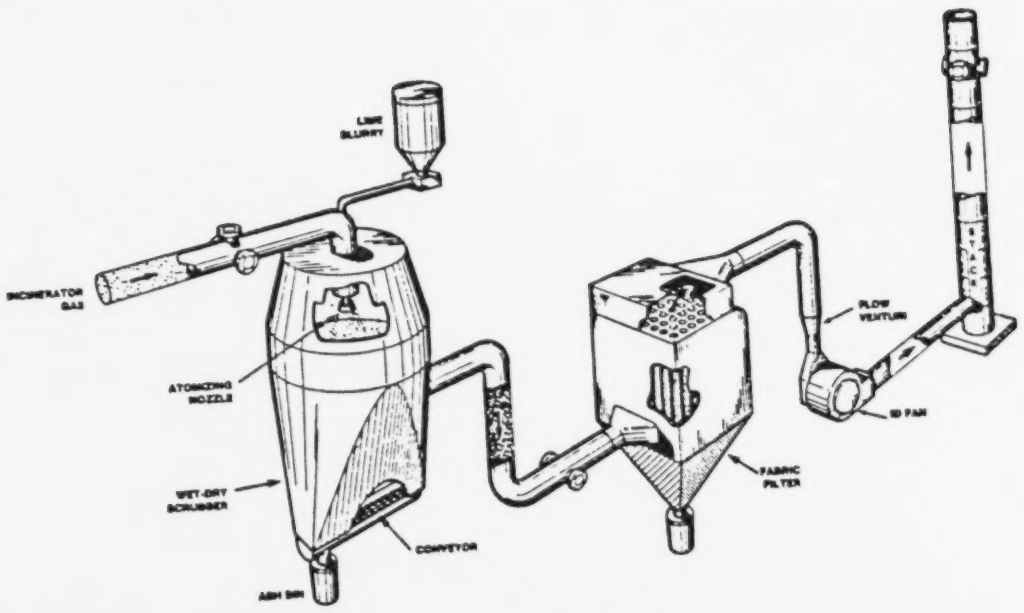

Figure 2. Wet-Dry System

TABLE 8. PCDD CONCENTRATIONS (ng/Nm^3 @ 8% O_2) IN FLUE GAS AND REMOVAL EFFICIENCIES[14]

	Dry System				Wet-Dry System	
Operating Condition	110°C	125°C	140°C*	>200°C	140°C	140°C + Recycle
Inlet (ng/Nm^3)	580	1400	1300	1030	1100	1300
Mid Point (ng/Nm^3)	310	570	540	1140	840	1270
Outlet (ng/Nm^3)	0.2	ND	ND	6.1	ND	0.4
Efficiency (%)						
- Inlet/Midpoint	47	60	57	-11	24	2
- Overall	>99.9	>99.9	>99.9	99.4	>99.9	>99.9

* Based on 1 test
ND = Not Detected

TABLE 9. PCDF CONCENTRATIONS (ng/Nm^3 @ 8% O_2) IN FLUE GAS AND REMOVAL EFFICIENCIES[14]

	Dry System				Wet-Dry System	
Operating Condition	110°C	125°C	140°C*	>200°C	140°C	140°C + Recycle
Inlet (ng/Nm^3)	300	940	1000	560	660	850
Mid Point (ng/Nm^3)	270	440	630	490	690	1030
Outlet (ng/Nm^3)	2.3	ND	1.0	1.2	ND	0.9
Efficiency (%)						
- Inlet/Midpoint	11	54	37	13	-4	-21
- Overall	99.3	>99.9	99.9	99.8	>99.9	99.9

* Based on one test
ND = Not Detected

fabric filter in removing these pollutants from the flue gas effluent. Similar results were found for the Wet-Dry System --- i.e., the fabric filter does the bulk of the job in removing the dioxins and the furans from the effluent.

Control of Other Organics

The performance of the 2 pilot plant Systems at Quebec City in removing chlorobenzenes (CBs), polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) and chlorophenols (CPs) is shown in Table 10. It shows that operating the Dry System at the lower temperatures yielded higher removal efficiencies (72 to over 99%) and that operating at over 200°C resulted in the lowest removals for the CBs, PCBs and the CPs. Table 10 also shows that removals were highest (typically over 99%) when the Wet-Dry System was utilized.

Control of Metals

Table 11 shows the inlet and outlet flue gas concentrations around the 2 Quebec City pilot units of the 8 metals that Environment Canada judged to be the most significant ones.[14] It can be calculated from this data that the collection/removal efficiencies for all the metals except Hg was greater than 99.9%. The removal efficiency for mercury ranged from 91 to 97% for 5 of the 6 test runs. In the sixth run, the one where the Dry System operated at over 200°C, no Hg was removed. Environment Canada felt it essential to operate these control systems below this temperature level to obtain the effective removal of mercury. Since the inlet values of overall particulate to the pollution control pilot plants ranged from 5560 to 7710 mg/Nm^3 (at 8% O_2), and the outlet values were always below 2 mg/Nm^3 during their pre-performance testing,[14] overall particulate removal efficiencies of the pilot units probably approximated 99.96% during their performances tests (if the outlet values continued at the low levels of 2 mg/Nm^3 and below during the performance tests).

Control of HCl and SO_2 Emissions

The removal of HCl and SO_2 from the flue gases from WTE plants was also studied by the Quebec City research team; the removal efficiencies they obtained during their pilot tests are shown in Tables 12 and 13.[14] The data shows that HCl removals were 98% when the Dry System was operated at 125°C or below. SO_2 removals were over 92% when in this temperature regime. Once again, the first stage alone was not very effective in achieving high removal efficiencies, except at the low operating temperature of 110°C.

TABLE 10. PERCENT REMOVAL OF OTHER ORGANICS[14]

	Dry System				Wet-Dry System	
	110°C	125°C	140°C*	>200°C	140°C	140°C + Recycle
CBs	95	98	98	62	>99	99
PCBs	72	>99	>99	54	>99	>99
PAHs	84	82	84	98	>99	79
CPs	97	99	99	56	99	96

* Based on one test

TABLE 11. INLET/OUTLET METAL CONCENTRATIONS ($\mu g/Nm^3$ @ 8% O_2)

		Dry System				Wet-Dry System	
Metal	Location	110°C*	125°C*	140°C*	>200°C	140°C	140°C + Recycle
Zinc (Zn)	Inlet	99,000	108,000	93,000	91,000	77,000	88,000
	Outlet	7	5	6	10	5	6
Cadmium (Cd)	Inlet	1300	1300	1500	1000	1200	1100
	Outlet	0.4	0.4	ND	0.6	ND	ND
Lead (Pb)	Inlet	41,000	44,000	34,000	35,000	36,000	34,000
	Outlet	4	3	5	6	1	6
Chromium (Cr)	Inlet	3100	1900	2000	1900	1400	1700
	Outlet	0.4	0.4	1	0.5	0.2	0.7
Nickel (Ni)	Inlet	1000	1800	1300	800	700	2500
	Outlet	1.3	0.4	0.7	2	1.3	2
Arsenic (As)	Inlet	150	100	130	80	110	130
	Outlet	0.02	0.04	0.04	0.07	0.04	0.03
Antimony (Sb)	Inlet	2000	800	1000	1500	1000	2200
	Outlet	0.2	0.4	0.6	0.5	0.3	0.6
Mercury (Hg)	Inlet	440	480	320	450	190	360
	Outlet	40	13	20	610	10	19

Note: Concentrations rounded off for simplicity.
* Based on one test, except for mercury, which is based on two tests.
ND - Not Detected

TABLE 12. HYDROGEN CHLORIDE CONCENTRATIONS (@ 8% O_2) AND REMOVAL EFFICIENCIES[14]

	Dry System				Wet-Dry System	
Flue Gas Temp. at Fabric Filter Inlet	110°C	125°C	140°C*	>200°C	140°C	140°C + Recycle
Stoichiometric Ratio	1.16	1.03	1.04	1.49	1.19	1.10
Inlet (ppm)	423[a]	464[b]	475[a,d]	392[b,d]	366[c]	470[a]
Midpoint (ppm)	15[a]	69[a]	129[a,d]	196[a,d]	149[a]	152[a]
Outlet (ppm)	7[a]	9[b]	29[a,d]	91[b,d]	29[a]	42[a]
Eff. to Midpoint (%)	96	85	73	50	59	68
Eff. Overall (%)	98	98	94	77	92	91

[a] Based on continuous gas monitors.
[b] Based on manual sampling (15-30 minute tests).
[c] Based on a combination of continuous gas monitors and manual sampling (15-30 minute tests).
[d] One test only.

TABLE 13. SULFUR DIOXIDE CONCENTRATIONS (@ 8% O_2) AND REMOVAL EFFICIENCIES[14]

	Dry System				Wet-Dry System	
Flue Gas Temp. at Fabric Filter Inlet	110°C	125°C	140°C*	>200°C	140°C	140°C + Recycle
Stoichiometric Ratio	1.16	1.03	1.04	1.49	1.19	1.10
Inlet (ppm)	119	118	99	117	106	106
Midpoint (ppm)	24	65	64	103	67	70
Outlet (ppm)	4	10	41	83	35	43
Eff. to Midpoint (%)	80	45	35	11	37	35
Eff. Overall (%)	96	92	58	29	67	60

*Based on one test

SUMMARY AND CONCLUSION

This Paper has discussed selected environmental standards which have been adopted by various countries and States for Waste-to-Energy (WTE) plants,[3-7] has described the pollutant emissions emanating from full-scale plants of this type,[8,9] and has delineated the pilot plant performance of two air pollution control technologies applied to the flue gases of such plants.[14]

The results of this review of selected, published literature reveal that the degree of pollution control possible for WTE plants and the emission level that remains after these controls are applied range as follows:

- Using Full-Scale Data[8,9]

Pollutant	Degree of Control Possible, %	Emission Levels After Controls, ng/Nm^3	
		Average	Range
• PCDD	Not Determined	4263[8]	0.01-13,000[9]
• PCDF	Not Determined	3850[8]	0.02-24,000[9]

- Using Pilot-Scale Data[14]

		Range
• PCDD	99.4 - >99.9	ND - 6.1
• PCDF	99.3 - >99.9	ND - 2.3
• CBs	62 - >99	100 - 2700
• CPs	56 - 99	230 - 8300
• PCBs	54 - >99	0.14 - 9.2
• PAHs	79 - >99	15 - 250
• Zn	~ 99.9%	5000 - 10,000
• Cd		ND - 600
• Pb		1000 - 6000
• Cr		200 - 1000
• Ni		400 - 2000
• As		20 - 70
• Sb		200 - 600
• Hg	91*- 97	10,000 - 40,000 *
• HCl	77 - 98	7 - 91 ppm
• SO_2	29 - 96	4 - 83 ppm
• CO	N/A	130 - 220 ppm

ND = Not detected; N/A = Not applicable

* = Neglecting the 610 ng/Nm^3 value gotten when the Dry System was operated over 200°C (see Table 11).

The residue characteristics have also been shown to range as follows (based on the pilot plant data of Environment Canada taken at Quebec City[14]):

Pollutant	Wet-Dry Scrubber Ash	Dry Scrubber Ash	Fabric Filter Ash
	----------Range in (in ng/g or ppb)----------		
• PCDD	6 - 14*	31 - 160	160 - 740*
• PCDF	4 - 12*	22 - 87	130 - 380*
• CBs	100 - 300	300 - 800	1700 - 3300
• CPs	100 - 300	400 - 1200	2700 - 8500
• PCBs	0.2 - 0.5	1.0 - 1.8	2.5 - 24
• PAHs	20 - 350	40 - 80	200 - 2300
• Zn	3800 - 5200	7500 - 8000	11,500 - 22,000
• Cd	30 - 40	65 - 70	160 - 340
• Pb	1200 - 1600	2000 - 2300	5000 - 9300
• Cr	170 - 250	270 - 340	160 - 220
• Ni	70 - 160	90 - 170	40 - 95
• As	4 - 7	5 - 10	14 - 50
• Sb	30 - 50	40 - 50	150 - 380
• Hg	2 - 8	22 - 38	75 - 300

(• Zn, • Cd, • Pb, • Cr, • Ni, • As, • Sb, • Hg: in μg/g or ppm)

* Pollutant range in ashes from Quebec City's "Dry System" and "Wet-Dry System" taken collectively.

REFERENCES

1. Huffman, G.L. and Liberick, W.W., "EPA's R&D Program in Pyrolytic Conversion of Waste-to-Fuel Products," presented at the American Chemical Society Symposium on Advanced Thermal Processes for Conversion of Solid Wastes and Residues, Anaheim, California, March, 1978.

2. Huffman, G.L., "Pyrolysis of Municipal and Industrial Waste," to be presented at the International Solid Waste and Public Cleansing Association Conference on Energy Recovery from Waste Materials, Milan, Italy, Spring, 1987.

3. McIlvaine, R.W., McIlvaine, M., and Carpenter, M., "Emissions Control Options in Waste-to-Energy Plants," in Waste Age, Volume 18, Number 1, January, 1987.

4. Personal communication with R.W. McIlvaine of The McIlvaine Company on March 9-12, 1987.

5. Seeker, W.R., Lanier, W.S., and Heap, M.P., "Municipal Waste Combustion Study: Combustion Control of Organic Emissions," draft report to the U.S. Environmental Protection Agency, January, 1987, and personal communication with W.R. Seeker on February 5, 1987.

6. Bergvall, G., "New Emission Limits for Waste-to-Energy Plants in Sweden," in Proceedings from the January 20-22, 1987 Copenhagen Seminar on Emission of Trace Organics from Municipal Solid Waste Incinerators.

7. New York State Department of Environmental Conservation, "Emission Source Test Report - Preliminary Report on Westchester Resource Recovery Facility," Albany, New York, January, 1986.

8. Ontario Ministry of the Environment, "Scientific Criteria Document for Standard Development No. 4-84: Polychlorinated Dibenzo-p-Dioxins (PCDDs) and Polychlorinated Dibenzofurans (PCDFs)," September, 1985.

9. Hasselriis, F., "Optimization of Combustion Conditions to Minimize Dioxin Emissions," in Proceedings from the January 20-22, 1987 Copenhagen Seminar on Emission of Trace Organics from Municipal Solid Waste Incinerators.

10. Visalli, J., "Pittsfield Incinerator Research Project, Status and Summary of Phase I: Plant Characterization and Performance Testing," ASME National Waste Processing Conference, Denver, Colorado, June, 1986.

11. Hay, D.J., Finkelstein, A. and Klicius, R., "The National Incinerator Testing and Evaluation Program: An Assessment of A) Two-Stage Incineration and B) Pilot-Scale Emission Control," APCA Annual Meeting, Minneapolis, Minnesota, June, 1986.

12. TUV, "Tests of Uncontrolled and Clean Gas and Discharged Salts of a MSW Incinerator for PCDD/PCDF," Hamburg, West Germany, 1984.

13. Boisjoly, L., "Measurement of Emissions of PCDD and PCDF from Des Carrieres Incinerator in Montreal," Report EPS 5/UP/RQ/-1, Environment Canada, December, 1984.

14. Environment Canada and Flakt Canada, Ltd., "The National Incinerator Testing and Evaluation Program: Air Pollution Control Technology," Report EPS 3/UP/2, September, 1986.